

## TIMING AND MAGNITUDE OF BROAD-WINGED HAWK MIGRATION AT MONTCLAIR HAWK LOOKOUT, NEW JERSEY, AND HAWK MOUNTAIN SANCTUARY, PENNSYLVANIA

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**ABSTRACT.**—The Broad-winged Hawk (*Buteo platypterus*) breeds in eastern and central Canada and the United States, and winters in Central America and northern and central South America. Birders and ornithologists count migrating Broad-winged Hawks at dozens of traditional watch sites throughout the northeastern United States. We modeled counts of migrating Broad-winged Hawks from two raptor migration watch sites: Montclair Hawk Lookout, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, to determine whether annual abundance and trend estimates from individual sites within the mid-Atlantic states are representative of the region as a whole. We restricted ourselves to counts made between 10:00 and 16:00 EST during September to standardize count effort between sites. We created one model set for annual counts and another model set for daily counts. When modeling daily counts we incorporated weather and identity of individual observers. Akaike's Information Criteria were used to select the best model from an initial set of competing models. Annual counts declined at both sites during 1979–1998. Broad-winged Hawk migration began, peaked, and ended later at Montclair than at Hawk Mountain, even though Hawk Mountain is 155 km west-southwest of Montclair. Mean annual counts of hawks at Montclair were more than twice those at Hawk Mountain, but were not correlated. Broad-winged Hawks counted at Montclair may not be the same birds as those counted at Hawk Mountain. Rather, the two sites may be monitoring different regional subpopulations. Broad-winged Hawks counted at the two sites may use different migration tactics, with those counted at Hawk Mountain being more likely to slope soar, and those at Montclair more likely to use thermal soaring. A system of multiple watch sites is needed to monitor various breeding populations of this widely dispersed migrant. Received 17 May 2002, accepted 24 August 2002.

The Broad-winged Hawk (*Buteo platypterus*) is a small, forest-dwelling, migratory buteo that breeds in central and eastern Canada and the United States and overwinters in Central America and northern and central South America (Goodrich et al. 1996). Migrating Broad-winged Hawks typically travel in loosely organized, cluster flocks (*sensu* Hepner 1974) that can include thousands and even tens of thousands of birds (Bildstein 1999, Zalles and Bildstein 2000). Most of their long distance flight consists of slope soaring and thermal soaring interspersed with interthermal gliding (Kerlinger et al. 1985, Bildstein 1999). During autumn, scattered opportunities for slope soaring along mountain ridges, and a lack of thermals over large bodies of water, concentrate migrants in many lo-

cations. In the U.S., large concentrations occur along the northern shores of the Great Lakes, the eastern edges of the Appalachian Mountains, the coastal zone of southern New England, and the coastal plain of southern Texas. Farther south, large concentrations occur along coastal Veracruz, Mexico, in southeastern Costa Rica, and over the Pacific slope of Panama (Sutton and Sutton 1999, Bildstein and Saborio 2000, Zalles and Bildstein 2000).

During the late 1990s, more than 150 raptor migration watch sites were recording the annual southbound movements of this species (Zalles and Bildstein 2000). However, most analyses of Broad-winged Hawk migration have focused on annual variation in counts at single watch sites (Kerlinger et al. 1985, Bednarz et al. 1990, Allen et al. 1996, Bildstein 1998). Our understanding of the geography of Broad-winged Hawk migration remains rudimentary, particularly regarding the extent of broad-frontal leading-line movements, and identity of source populations of birds counted at particular watch sites (Kerlinger et al. 1985, Zalles and Bildstein 2000).

We were specifically interested in whether

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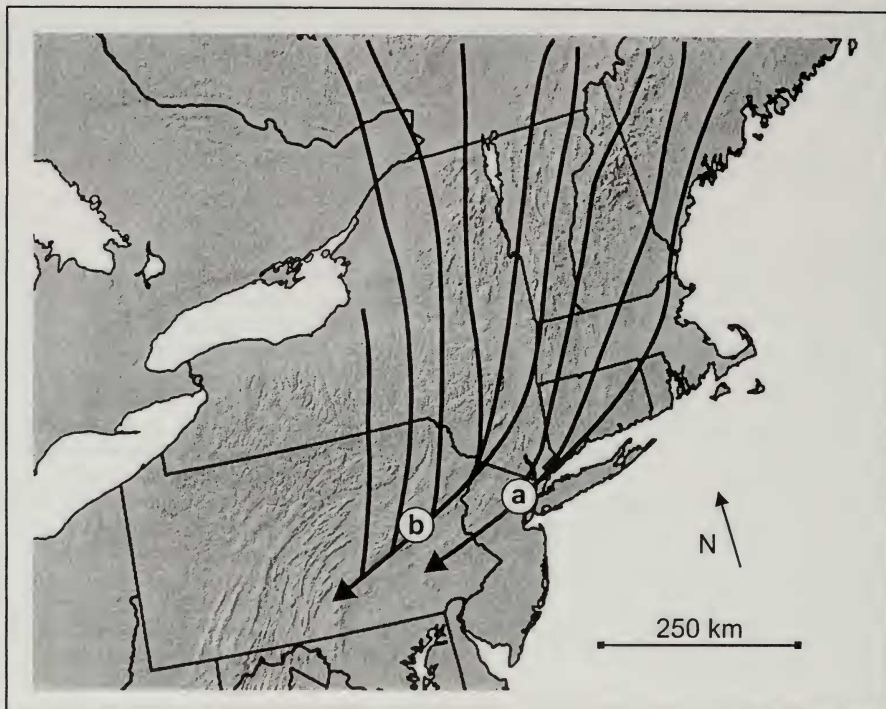


FIG. 1. Locations of Montclair Hawk Lookout (a) and Hawk Mountain Sanctuary (b), with hypothesized flight lines of migrating Broad-winged Hawks in the region.

annual counts of Broad-winged Hawks made from a single watch site were representative of the autumn migration in the northeastern U.S., and therefore suitable alone for monitoring that population. Thus, we compared the timing and magnitude of the autumn flight of Broad-winged Hawks at two ridgetop watch sites in eastern North America along approximately the same latitude but separated longitudinally by approximately 155 km. Hawk Mountain Sanctuary is an inland raptor migration watch site in the central Appalachian Mountains of eastern Pennsylvania (Bildstein 1998). Montclair Hawk Lookout is a coastal lowland watch site in northeastern New Jersey (Zalles and Bildstein 2000).

If Broad-winged Hawks migrate southwest along a broad front through northeastern North America, we predicted the magnitude and timing of migration at the two sites would correlate, with the timing of movements at Hawk Mountain lagging that of Montclair. If instead regional subpopulations of Broad-winged Hawks migrate independently of each other, then the magnitude of the flight at the

two sites would vary independently, and the timing of the flight at Hawk Mountain need not lag that of Montclair.

## METHODS

We analyzed autumn migration counts of Broad-winged Hawks from Montclair Hawk Lookout and Hawk Mountain Sanctuary. Montclair Hawk Lookout (155 m elevation) is in northeastern New Jersey (40° 50' N, 74° 12' W; Fig. 1), 30 km northwest of New York City, on First Watchung Mountain, the first ridge west of the lowermost Hudson River. Hawk Mountain Sanctuary is a 465-m ridgetop watch site along the Kittatinny Ridge in eastcentral Pennsylvania (40° 38' N, 75° 59' W), 170 km west of New York City (Broun 1949).

Migrating Broad-winged Hawks have been counted at Hawk Mountain since 1936 (excluding 1943–1945), and at Montclair Hawk Lookout since 1957 (Zalles and Bildstein 2000). Both sites conduct migration counts on most days from at least 1 September through mid-November. Annual counts at both sites regularly exceed 8,000 birds. We restricted our analysis to counts made during 1979–1998, in part because the number of count days at Montclair increased from 22 to 86 days during 1966–1974 but remained relatively constant thereafter (varying between 86 and 103 days). Also, the 1978 count at Hawk Mountain was anoma-

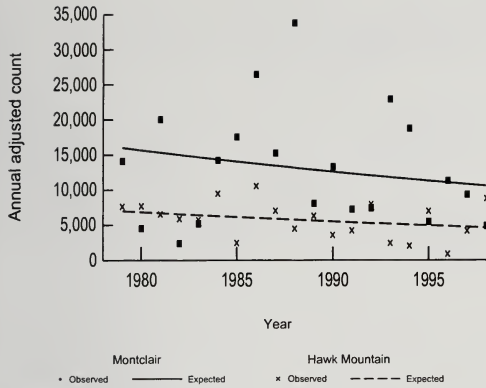


FIG. 2. Adjusted counts of Broad-winged Hawks observed and expected each September at Montclair Hawk Lookout, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, 1979–1998.

lously large (i.e., 98% larger than the next largest count of Broad-winged Hawks ever recorded at Hawk Mountain). We felt including this outlier could bias our results.

Annual counts from both sites were modeled together by including a site variable in the model. Counts often did not begin or end at the same time of day at both sites. We therefore standardized count effort between sites by restricting analyses to birds counted during September between 10:00 and 16:00 EST.

We also modeled daily counts adjusted for effort. A set of 11 competing models was created. Most of these models included site, year, and day of year. Some models of daily counts included primary observer, maximum visibility, wind direction, or change in temperature or cloud cover during the previous 24 h (Sauer et al. 1994, Allen et al. 1996), using weather data collected at noon. The observer assigned for a given day was the most experienced official counter present at noon.

We conducted model selection of annual and daily counts by first constructing a global model including all variables (Burnham and Anderson 1998). Parameters were estimated using SASRALPH (ver. 16, November 2000, available from G. Pendleton, Alaska Dept. of Fish and Game, Douglas). SASRALPH models count data using generalized linear models, a Poisson distri-

bution, no intercept, and a variation of Proc GENMOD in SAS to adjust for overdispersion (Link and Sauer 1997, SAS Institute, Inc. 1997). We conducted model selection using Akaike's Information Criterion corrected for small sample size (AIC<sub>c</sub>, Burnham and Anderson 1998). The AIC finds an optimal balance between model fit (i.e., number of parameters) and precision (i.e., bias). The model with the lowest AIC<sub>c</sub> value was considered best.

Variables potentially unrelated to trend were removed from the global model one at a time. If the resulting constrained model had a lower AIC<sub>c</sub> value than the more general model, we permanently discarded the variable under consideration. Otherwise, we retained that variable. We estimated Akaike weights for each model and examined model-averaged parameter estimates if no model had an Akaike weight >0.95 (Anderson et al. 2001, Burnham and Anderson 1998).

We compared the timing of migration between sites by modeling mean daily counts during 1979–1998 using Proc GENMOD with a normal distribution and an identity link. We also compared the mean daily cumulative percent of the annual flight at each watch site. Lastly, we tested for a correlation between annual adjusted total counts at the two sites using Proc GENMOD with a Poisson distribution. Standard errors of parameter estimates are reported unless stated otherwise.

## RESULTS

During 1979–1998 mean annual Broad-wing Hawk counts at Montclair ( $\bar{x} = 13,119$ ,  $SD = 8,260$ ) were more than twice those at Hawk Mountain ( $\bar{x} = 5,716$ ,  $SD = 2,653$ ). The best model of annual counts included a site effect ( $\beta_{\text{Montclair}} = 9.47 \pm 0.15$  versus  $\beta_{\text{Hawk Mountain}} = 8.64 \pm 0.10$ ,  $P < 0.001$  for both sites,  $df_{\text{Montclair}} = 1$ ,  $\chi^2_{\text{Montclair}} = 4,175$ ,  $df_{\text{Hawk Mountain}} = 1$ ,  $\chi^2_{\text{Hawk Mountain}} = 6,873$ ) and a negative year effect ( $\beta_{\text{year}} = -0.02 \pm 0.02$ ,  $P = 0.14$ ,  $df = 1$ ,  $\chi^2 = 2.21$ ; Fig. 2), but no site  $\times$  year interaction, suggesting that counts at both sites declined during this period (Table 1). Model-averaged parameter estimates were virtually identical to those given above.

The best model of daily counts during

TABLE 1. Models of annual adjusted counts of Broad-winged Hawks at Montclair Hawk Lookout, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, during 1979–1998. A total of 40 observations were used in these models.

Model number	Model	Number of parameters	AIC <sub>c</sub>	Delta AIC <sub>c</sub>	Akaike weight
1	site + year	3	745.810	0.00	0.42
2	site	2	746.243	0.43	0.34
3	site + year + year $\times$ site	4	746.930	1.12	0.24

TABLE 2. Models of daily adjusted counts of Broad-winged Hawks at Montclair Hawk Lookout, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, during 1979–1998. A total of 948 observations were used in these models.

Model number	Model	Number of parameters	AIC <sub>c</sub>	Delta AIC <sub>c</sub>	Akaike weight
1*	site + julian × site + visibility	7	10812.5	0.00	0.59
2	julian × site + visibility	6	10814.8	2.28	0.26

\* Expected values from this model were identical to those from a model with: site + julian + julian × site + visibility.

1979–1998 included site, day, site × day, and maximum visibility (Tables 2 and 3). No annual trend was detected. The flight tended to be smaller at Montclair than at Hawk Mountain during the first week of September, but larger at Montclair than at Hawk Mountain later in the month. Fewer birds were counted on very hazy days, when maximum visibility was <3.2 km.

The Akaike weight for the lowest AIC<sub>c</sub> model of daily counts was more than twice that of the next best model (0.59 versus 0.26; Table 2). The second-best model of daily counts differed from the best model only in not including a main site effect. No other model had an Akaike weight >0.07 and we report only the two best models. All models including observer effects or weather variables, other than maximum visibility, had no support (Akaike weight = 0). Model-averaged parameter estimates were similar to those in the lowest AIC<sub>c</sub> model.

Our most general model of mean daily counts had an Akaike weight = 1.0, and only this model is reported. The model included significant site ( $\beta_{\text{Montclair}} = 7.04 \pm 0.10$ ,  $\beta_{\text{Hawk Mountain}} = 6.26 \pm 0.10$ ,  $P < 0.001$  for both sites,  $df_{\text{Montclair}} = 1$ ,  $\chi^2_{\text{Montclair}} = 5,475$ ,  $df_{\text{Hawk Mountain}} = 1$ ,  $\chi^2_{\text{Hawk Mountain}} = 3,824$ ), day ( $\beta_{\text{day}} = 0.02 \pm 0.02$ ,  $P = 0.27$ ,  $df = 1$ ,  $\chi^2 = 1.20$ ), and day<sup>2</sup>

( $\beta_{\text{day} \times \text{day}} = -0.02 \pm 0.00$ ,  $P < 0.001$ ,  $df = 1$ ,  $\chi^2 = 127$ ) effects, as well as a site × day interaction ( $\beta_{\text{Montclair}} = 0.06 \pm 0.03$ ,  $P < 0.001$ ,  $df = 1$ ,  $\chi^2 = 5.46$ ; Fig. 3). The model suggested that Montclair counts peaked several days later than did those at Hawk Mountain.

Examination of mean cumulative daily proportion of the flight during 1979–1998 also suggested a seasonal difference in the flight between the two sites. Eighty percent of the flight at Hawk Mountain passed by 20 September, whereas 80% of the flight at Montclair had not passed until 22 September. A paired *t*-test on annual median date of the flight also indicated the flight at Montclair lagged that at Hawk Mountain by 2.00 days during 1979–1998 (SE = 0.88,  $P = 0.035$ ,  $t = 2.27$ ,  $n = 20$ ). There was no significant association between total annual counts at the two sites ( $P = 0.54$ ,  $df = 18$ ,  $\chi^2 = 0.37$ ).

## DISCUSSION

Migrating Broad-winged Hawks start to aggregate into large flocks almost as soon as they begin migrating south (Bildstein 1999). As a result, more than half of each year's autumn flight can pass a watch site in 2–4 days, while on many other days during traditional peak passage (i.e., mid- to late September), few birds may be seen (Hawk Mountain Sanc-

TABLE 3. Best model of adjusted daily counts of Broad-winged Hawks at Montclair Hawk Lookout, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, September 1979–1998.

Parameter	Level	df	Estimate	SE	$\chi^2$	<i>P</i>
Site	Montclair	1	0.22	3.97	0.003	0.95
	Hawk Mountain	1	4.48	3.28	1.88	0.17
Site × Day	Montclair	1	0.02	0.02	2.40	0.12
	Hawk Mountain	1	0.00	0.01	0.07	0.79
Visibility	Very Hazy	1	-1.42	0.46	9.54	<0.01
	Hazy	1	-0.27	0.28	0.88	0.35
	Clear	1	0.07	0.22	0.10	0.75
	Very Clear	0	0.00	0.00	—	—

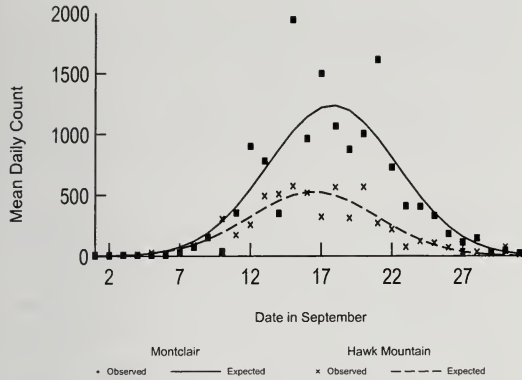


FIG. 3. Mean adjusted daily counts of Broad-winged Hawks observed and expected each September at Montclair Hawk Lookout, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, 1979–1998.

tuary unpubl. data). Extreme variation in daily counts and, to a lesser degree, marked variation in annual counts at a given site make it difficult to construct explanative models for the flight. Such extreme variation in daily counts may explain why we detected a decreasing trend with annual counts but not with daily counts.

Hawk Mountain is 155 km west-southwest of Montclair. Most Broad-winged Hawks are thought to move generally southwest across the region (Hagar 1988), so we predicted *a priori* that the migration at Hawk Mountain would peak after that at Montclair. That our results were not consistent with this prediction, and annual counts at the two sites were not correlated, suggests that the two watch sites are along different flight corridors, and that birds seen at one site are not likely to be seen at the other. The migration delay along the coast could be due to an ameliorated coastal climate prolonging conditions suitable for thermal generation, thereby permitting later migration times. However, this would not explain the lack of a correlation between annual counts at the two sites.

Broad-winged Hawks counted at Montclair may represent birds traveling south and southwest from eastern New England and the Maritime Provinces of Canada, whereas those passing Hawk Mountain represent birds traveling from Pennsylvania, New York, western New England, Ontario, and Quebec (Fig. 1). Such a scenario makes sense topographically

(Kerlinger 1989). Hawks counted at Montclair may alternately slope soar along the ridges of the northern Appalachians and thermal soar and glide across the coastal lowlands to the southeast, whereas hawks counted at Hawk Mountain may primarily slope soar along the ridges of the Adirondack, Catskill, Pocono, and northwestern and central Appalachian mountains (Fig. 1).

Alternatively, birds observed at Montclair may have come from a large northern breeding area and wind drifted toward the coast where they would face the water barrier of Long Island Sound and begin to concentrate (Fogleman 1993). If so, the annual timing and magnitude of the flight at Montclair may be more influenced by the presence or absence of wind drift than the flight at Hawk Mountain. Satellite telemetry could be used to test between these hypotheses.

Another possible explanation for flight differences between the two sites is that adults might comprise most of the flight at Hawk Mountain, while juveniles might comprise most of the flight at Montclair, and that both sites draw upon birds from the same geographic region. However, casual observations have provided no indication that most of the Broad-winged Hawks counted at Montclair are juveniles (EMG and WG pers. obs.). Furthermore, observations at Hawk Mountain suggest that juvenile Broad-winged Hawks migrate earlier, not later than adults (Goodrich et al. 1996).

If regional breeding subpopulations of Broad-winged Hawks exist in the northeastern United States and Canada, successful monitoring and conservation efforts on their behalf will depend upon delineating those populations either on the breeding grounds, on the wintering grounds, or in both areas. This may be particularly important given that annual counts at both Montclair and Hawk Mountain appear to be declining. Even upon identification of possible separate populations, monitoring these populations may be possible only by using systematic counts at raptor migration watch sites. Our results suggest that a network of complementary migration watch sites is needed for effective monitoring of populations of this widely dispersed flocking migrant.

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